A Survey of Recommendation Algorithms Based on Knowledge Graph Embedding

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***Abstract*—Recommender system is able to realize personalized information filtering, which is a key way for knowledge discovering in information-rich environment. Knowledge graphs contain rich semantic associations between entities, which can be utilized to strengthen relationships between recommended items and bring interpretability for recommendation. With the establishment of knowledge graphs in various fields, the increasing numbers of researchers have carried out studies on recommendation algorithm based on knowledge graphs. Among them, recommendation algorithm based on knowledge graph embedding is a kind of simple and effective way to introduce knowledge entities and their relation into traditional recommender system. In this paper, the study about this kind of studies is summarized by analysis of existing literatures. We discuss and compare several studies, and the key elements of these algorithms are statistically analyzed.**

Keywords—Recommendation algorithm, knowledge graph embedding, feature vector

I. INTRODUCTION

With an explosive increase in global information, recommender system technique has been a focus of the new century computer science and technology research. recommender system is able to realize personalized information filtering, which is a key way for knowledge discovering in information-rich environment. In many scenarios(such as news recommendation), there may be richer knowledge in recommended items. Nevertheless, we can find that traditional recommender systems have no enough capability to reflect these knowledge, yet the entities and correlation between them can improve accuracy of recommendation algorithms.

A knowledge graph is a multi-relational graph composed of entities as nodes and relations as different types of edges, which describe various entities or concepts and their relationships[1]. Knowledge graphs have become important resources to support many artificial intelligence related applications, such as web/mobile search, Q&A, etc. Knowledge Graphs contain rich semantic associations between entities, so as to strengthen relationships between recommended items and bring interpretability for recommendation.

With the establishment of knowledge graphs in various fields, the increasing numbers of researchers have carried out studies on recommendation algorithm based on knowledge graphs, which has become a hot topic in current recommender system researches [2]. Especially, recommendation algorithm based on knowledge graph embedding is a kind of simple and effective way to introduce knowledge entities and their relation into traditional recommender system, which is the focus of this paper.

The rest of the article follows. In Section 2, we list the related studies about recommender system based on knowledge graph. In Section 3, we discuss and compare several studies of recommendation algorithm based on knowledge graph embedding, and the key elements of these algorithms are statistically analyzed. Finally, the conclusions are drawn.

II. RELATED WORKS

According to the expression form of knowledge graph in the recommending process, current recommender system based on knowledge graph can be roughly divided into three categories: recommendation based on ontology, recommendation based on linked open data and recommendation based on knowledge graph embedding.

In the first methods, in order to more precisely represent entity, ontology is utilized to describe concept hierarchy. Then, ontology is incorporated into content-based recommendation method[3] and collaborative filtering method [4]. However, the construction of ontology is a time-consuming task and need to be depend on expert. In the second methods, rich semantic information in linked open data is introduced into existing recommendation algorithms, which focuses on user preferences, attribute similarity between items. In reference [5] , Wang et al. proposed a park recommendation model and rating (PRMRR) based on user reviews, which effectively improved the quality of park suggestions and the existing data sparsity problems. As the recommending process of these methods depends on external data, the completeness of external data affects the recommendation results tremendously.

In recent years, a promising approach for recommendation is embedding a knowledge graph into a continuous vector space while preserving certain information of the graph, so as to simplify the operation while maintaining the inherent structure of knowledge graph [6]. This kind of methods can enrich information of user and items by associating them with relevant entity in the knowledge graph, and is easy to be realized. For the moment, although relatively few studies were carried on this field, they are becoming increasingly popular.

III. Recommendation Algorithm Based on Knowledge Graph Embedding

A. The key elements of categories

Through comparative analysis several studies of this field, we found that there are four key elements decided the way of knowledge graph embedding introduction: knowledge graph embedding method adopted, incorporated recommendation algorithm, jointly learning / independently learning and user-based/item-based. The relationship of these elements is shown Figure 1.

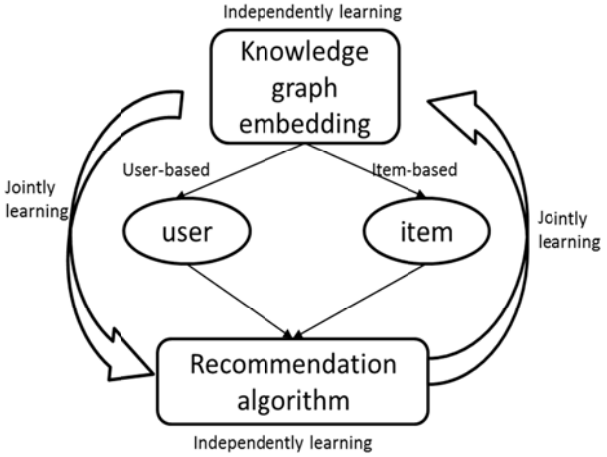

Fig. 1. The relationship of four elements

- knowledge graph embedding can represent entities and relations in a continuous vector space, and defines a scoring function to measure its plausibility[6]. Then, entity and relation vector representation can be obtained by maximizing the total plausibility. Finally, the embedding representations can be used to serve for user or item's similarity. With different scoring functions, knowledge graph embedding algorithms vary between simple difference[7], translation[8], nonlinear transformations [9] and so on.
- In general, the introduction of knowledge graph embedding into recommender system is usually based on traditional recommendation algorithms, such as collaborative filtering algorithms, content-based algorithms and hybrid algorithms. knowledge graph embedding is only for supplementation of user or item information.
- According to the relationship between knowledge graph embedding and recommendation algorithm. There are two main ways to realize knowledge graph embedding learning and recommending -- independently learning and jointly learning. For independently learning, entity vectors and relationship vectors are obtained firstly, and then these low-dimensional vectors are introduced into the recommender system to learn user vectors and item vectors. Its advantage is that the learning module of knowledge graph embedding and the recommendation algorithm module can be used independently without disturbing each other. The disadvantage is that the end-to-end learning cannot be achieved in this method.
- In traditional recommender system, both user and item are able to be extracted feature for computing similarity. Likewise, the knowledge information is involved in user and item descriptions. Therefore, knowledge graph embedding can be used in user information as well as items.

B. The concrete analysis of studies

In reference [10], Wang et al. proposed a Deep Knowledge-Aware Network (DKN), which depended on jointly learning. Firstly, this study enrich the information of the knowledge graph by associating each word in the news content with the related entities in the knowledge graph, and then merging the word level merge through the designed knowledge-aware convolutional neural network (KCNN). Therefore, the knowledge graph embedding is only introduced into item information. Meanwhile, the knowledge graph feature learning was combined with the objective function of the recommendation algorithm, and the end-to-end method was used for jointly learning. the advantage of this way is that the monitoring signal of the recommendation system module can be fed back to the knowledge graph feature learning, but the disadvantage is that the combination mode of the two modules in the final objective function and the weight distribution need to be determined by careful experiments. In this study, the knowledge-aware embedded vector is obtained by TransD method, and finally an attention model is adopted to generate recommendation results.

In reference[11], researchers utilize knowledge graph embedding method TransR to extract the item structure future. Meanwhile, a autoencoder is adopted to extract text vector and visual vector of items. Finally, three kinds of vectors were fused for constructing item latent vector. The knowledge graph embedding and recommendation algorithm are independently.

In reference [12], researchers utilized a memory neural network fused knowledge graph information for products recommendation in shopping site. Similarly, this study focus on item information and transforms corresponding entities to feature vectors. The knowledge graph embedding and recommendation algorithm are independently.

In reference [13], researchers propose a collaborative knowledge base embedded model (CKE) for recommendation tasks, which is belong to jointly learning . In this study, there are various kinds of knowledge: structural knowledge, text knowledge and visual knowledge. Firstly, the heterogeneous network embedding method TransR is used to extract the project structure catalog. Secondly, using the deep learning-based embedding technology(denoising autoencoder), the text representation and visual representation of the project are extracted. Finally, three kinds of vectors were fused for constructing item latent vector, and a collaborative filtering algorithm was utilized to generate recommendation results. The advantage of this framework is that it can extract feature representations from the knowledge base at the same time, capture the implicit relationship between the user and the project, and greatly improve the recommended performance.

In reference [14], Wang et al. focus on the problem of sentiment prediction. To address this problem, this study investigates how to predict possibly existing sentiment links in the presence of heterogeneous passage. First, because of the lack of explicit sentiment links in mainstream social

networks, it establishes a labeled heterogeneous sentiment dataset, which consists of users' sentiment relation, social relation and personal knowledge by entity-level sentiment extraction way. Then it shows an end-to-end Signed Heterogeneous Information Network Embedding (SHINE) framework to extract users' latent representations from heterogeneous networks and predict the sign of undetected sentiment links. SHINE utilizes multiple deep autoencoders to map every user into a low-dimension feature space, and preserves the network structure at the same time. Therefore, it belongs to a jointly learning method.

In reference [15],researchers propose a method called entity2rec to learn the relationship between users and items from the knowledge graph. Given the knowledge graph, a feature-based learning method is used to obtain the attribute-specific relevance score, and then the ranking methods are combined to generate a global user-item correlation measure. Finally, recommendations were generated by applying the top-N algorithm.

In reference [16], based on Electronic medical records(EMRs) and two medical knowledge graphs (ICD-9 ontology and DrugBank), researchers proposes a medical recommendation framework (SMR). The recommendation process begins by constructing a large heterogeneous graph of the obtained EMRs and medical knowledge graphs, where the nodes are drugs, diseases, patients, and the connections are various relationships between nodes. The generated patient-medical bipartite graph, patient-patient bipartite graph, medical knowledge graph, and disease knowledge graph are then embedded into the shared low-dimensional space. Finally, the new patient represented by the diagnostic vector is used as a node to recommend safe and effective drugs. The medical recommendation methods include rule-based recommendation and recommendation based on supervised learning methods.

In reference [17], an end-to-end framework called RippleNet was proposed. In this study, the user-item is first represented as an interaction matrix. The entity-relationship-entity is represented as a triplet, and then a large number of triples constitute the knowledge graph. The history set of interest to the user is treated as a seed of the knowledge graph, and then a ripple set is formed along the ripple extension for iteratively interacting with the item to obtain user-to-item correlation. The loss function generated in the process is iteratively optimized using the stochastic gradient descent algorithm. It is can be seen that this kind of path-based method is different from above feature-based studies. It overcomes the limitations of existing embedded by introducing preference propagation.

TABLE I. STATISTIC OF STUDIES

Title of the paper	Knowledge Graph embedding method	Recommendation algorithm	Jointly learning / independent learning	User based/item based
DKN_ Deep Knowledge-Aware Network for News Recommendation	TransD	Attention model	Jointly learning	Item based
Collaborative knowledge base embedding for recommender systems	TransR	Collaborative filtering	Jointly learning	Item based
entity2rec: Learning User-Item Relatedness from Knowledge Graphs for Top-N Item Recommendation	node2vec	Top-K	Jointly learning	User and Item based
Safe Medicine Recommendation via Medical Knowledge Graph Embedding	TransR	Top - K Rule-based recommendation	Jointly learning	User and Item based
Ripplenet Propagating user preferences on the Graph for Recommender Systems	Path-based	Preference propagation	Independently learning	User and Item Based

IV. CONCLUSIONS

In conclusion, the above studies demonstrated that recommendation algorithm based on knowledge graph embedding is an simple and efficient way for introducing user and item knowledge entities into recommendation.. This paper summarize the related studies and analysis the key elements of recommending process. These algorithms discussed in this paper also are descripted based on these key elements . However, there is relatively few studies in this field, then which deserve to be further explored. The studies of recommender system based on knowledge graph is just the beginning, more researches about improved algorithm are urgently needed. This kind of recommendation algorithms has enormous potential applications in widely fields.

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REFERENCES

[1] Wang Z , Zhang J , Feng J , et al. Knowledge Graph Embedding by Translating on Hyperplanes[C]// Twenty-eighth Aaai Conference on Artificial Intelligence. AAAI Press, 2014.

[2] Wang, H., Zhang, F., Zhao, M., Li, W., Xie, X., & Guo, M.. Multi-Task Feature Learning for Knowledge Graph Enhanced Recommendation. The Web Conference, 2019

[3] LI Dongsheng, LV Qin, XIE Xing, et al. Interest-based real-time content recommendation in online social com-munities[J]. Knowledge-based systems, 2012, 28: 1–12.

[4] YIN Jian, WANG Zhisheng, LI Qi, et al. Personalized recommendation based on large-scale implicit feedback[J].Journal of software, 2014, 25(9): 1953–1966.

[5] Wang, C., Wang, H., Pi, J., & An, L. Park Recommendation Algorithm based on User Reviews and Ratings. International Journal of Performability Engineering, 15(3), 803.2019

[6] Wang, Q., Mao, Z., Wang, B., & Guo, L. Knowledge Graph Embedding: A Survey of Approaches and Applications. IEEE Transactions on Knowledge and Data Engineering, 29(12), 2724‑2743, 2017

[7] Bordes A , Glorot X , Weston J , et al. A semantic matching energy function for learning with multi-relational data[J]. Machine Learning, 2014, 94(2):233-259.

[8] Bordes, A.; Usunier, N.; Garcia-Duran, A.; Weston, J.; and Yakhnenko, O. 2013a. Irreflexive and hierarchical relations as translations. arXiv preprint arXiv:1304.7158

[9] Socher R , Chen D , Manning C D , et al. Reasoning With Neural Tensor Networks for Knowledge Base Completion[C]// International Conference on Neural Information Processing Systems. Curran Associates Inc. 2013.

[10] Wang, H., Zhang, F., Xie, X., & Guo, M.. DKN: Deep Knowledge-Aware Network for News Recommendation. In WWW ’18 Proceedings of the 2018 World Wide Web Conference (pp. 1835‑1844),2018.

[11] Lin, Y., Liu, Z., Sun, M., Liu, Y., & Zhu, X.. Learning entity and relation embeddings for knowledge graph completion. In AAAI’15 Proceedings of the Twenty-Ninth AAAI Conference on Artificial Intelligence (pp. 2181–2187), 2015

[12] Huang J, Zhao W X, Dou H, et al. Improving sequential recommendation with knowledge-enhanced memory networks[C]. The 41st International ACM SIGIR Conference on Research & Development in Information Retrieval. Tokyo, Japan,2018: 505-514.

[13] Zhang, F., Yuan, N. J., Lian, D., Xie, X., & Ma, W.-Y. Collaborative Knowledge Base Embedding for Recommender Systems. In Proceedings of the 22nd ACM SIGKDD International Conference on Knowledge Discovery and Data Mining (pp. 353‑362).2016

[14] Wang H, Zhang F, Hou M, et al. Shine: Signed heterogeneous information network embedding for sentiment link prediction[C]. Proceedings of the 11st ACM International Conference on Web Search and Data Mining. Los Angeles, USA,2018: 592-600.

[15] Palumbo, E., Rizzo, G., & Troncy, R.. entity2rec: Learning User-Item Relatedness from Knowledge Graphs for Top-N Item Recommendation. In Proceedings of the Eleventh ACM Conference on Recommender Systems (pp. 32‑36).2017

[16] Wang M , Liu M , Liu J , et al. Safe Medicine Recommendation via Medical Knowledge Graph Embedding[J]. 2017.

[17] Wang, H., Zhang, F., Wang, J., Zhao, M., Li, W., Xie, X., & Guo, M. RippleNet: Propagating User Preferences on the Knowledge Graph for Recommender Systems. In Proceedings of the 27th ACM International Conference on Information and Knowledge Management (pp. 417‑426).2018